Physical properties of a model set of solid, texture-modified foods

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Physical properties of a model set of solid, texture-modified foods

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Abstract

Those suffering from swallowing disorders, or dysphagia, require texture-modified foods for safe swallowing. The texture is modified according to the severity of the disorder, as maintained by the guidelines outlining classes of texture-modified foods, ranging from viscous soups to soft, solid foods. As a basis for studies of bolus rheology and oral response of solid texture-modified foods, a set of well-defined, solid foods has been identified and characterized regarding texture and physical properties. Gelled food is compared to both the firmer timbale class and to the corresponding regular food. Foods eaten at room temperature were chosen to avoid temperature effects: bread, cheese, tomato, and the combination into a sandwich. All foods were tested as gel, timbale, and regular food. The texture was determined by compression and penetration tests, thereby showing a decrease in strength (compression stress), stiffness (modulus), and penetration force for increased degree of modification. The moisture content increased with increased degree of modification. The structural change from room to oral temperature was monitored by the complex shear modulus that showed a decrease with increasing temperature. Cheese and the gelatine-based tomato gel showed a distinct melting when the temperature was increased to 37°C. The texture-modified foods were softer and moister in all aspects as compared to the regular foods, which follows the intended modification. The classes for the texture-modified foods were qualitatively comparable to other national classification systems with regard to solid foods, but there is a lack of objective, physics-based classification of texture, especially for solid, texture-modified foods.

KEYWORDS
dysphagia, fracture, rheology, solid food, texture, texture-modification

1 | INTRODUCTION

The complete chewing and swallowing process is an intricate combination of voluntary and involuntary actions. For healthy individuals, it is an integral part of our food processing, one we seldom notice unless the swallowing is unpleasant or goes wrong. On the other hand, for individuals suffering from swallowing disorders, it is a daily struggle during every meal. Swallowing disorders, or dysphagia, is a growing problem, especially as the population ages. Already over the age of 50 years old, 22% of the population suffer from swallowing disorders

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and in the age group above 70 years old, 40% suffer due to factors such as degenerative diseases, side effects of medication, or simply age-related impairment of physiological oropharyngeal function leading to an overall prevalence of dysphagia of 8% (Cichero et al., 2013; Cook & Kahrilas, 1999). In addition to the elderly, patients with neurological diseases and patients with head and neck diseases are the main groups that commonly suffer from dysphagia (Gallegos, Brito-de la Fuente, Clavé, Costa, & Assegehegn, 2017). For the elderly suffering from dysphagia, symptoms vary from light inconvenience and coughing to inability to swallow any solid food. The common denominator, however, is that they all require texture-modified foods, sometimes together with other means such as modification of the breath-swallow pattern.

Texture-modified food should be soft, moist, smooth, and easy to chew and swallow. It should also not be sticky or adhesive, nor leave residues that could potentially lead to aspiration after swallowing (Sungsinchai, Niamnuy, Wattanapan, Charoenchaitrakool, & Devahastin, 2019). The severity of dysphagia is reflected in the degree of texture modification, ranging from soft, regular food for light symptoms to fluid foods for serious symptoms. There are guidelines for different classes of texture-modified foods implemented in both clinical and health care, but the classification systems are still national rather than international. Historically the texture modification has commonly meant mashing the food into a purée, and the available classification systems are therefore more detailed for fluid and semi-solid foods than for solid foods (Ekberg, 2019). The same holds for thickened fluids, but these are outside the scope of the present article which focuses on solid food.

In the present study, the texture-modified, solid foods follow the Swedish guidelines and belong to the classes "regular," "timbale," and "gel food" (Möller, 2007; Wendin et al., 2010). The Swedish classification system is similar to the Japanese Dysphagia Pyramid and both consider food texture as well as particle size (Fujitani et al., 2013; Matsuo & Fujishima, 2020). The Swedish classification of solid food includes "pâté" (soft texture, particles up to ~4 mm), "timbale" (soft texture, edible without using teeth, particles <1 mm), and "gel food" (soft gel, no particles), all of which are available as ready-made meals. The Swedish system also includes soups as "thin liquid" and "thick liquid," but the focus here is solid food. Components as well as the puréed ingredients and recipes are available (Findus Special Foods, 1999). The most commonly prescribed class for seniors is "timbale" as "paté" is often covered by soft, regular food. "Gel food" is mainly administered when needed in a clinical setting. The Japanese Dysphagia Pyramid code 4 is similar to pâté, code 3 to timbale and has two codes for gel food, code 0j (training food) and code 1j. It also has a code 2 for food in the form of a paste (2-1, smooth, particles <0.85 mm and 2-2, containing soft grains, with particles).

The National Dysphagia Diet (NDD), published by the American Dietetic Association, is often cited for thickened fluids and also describes one level of texture-modified, solid food, "Level 3, Dysphagia Advanced" for soft, moist foods as a transition to a regular diet (National Dysphagia Diet Task Force, 2002). The NDD Level 3 corresponds to the timbale class. Other levels refer to mashed or minced food, or thickened fluids. Similarly, the UK and Australian Food Texture Scales mainly describe mashed foods and thickened fluids, but have a "Texture A – Soft" (Australian) and a "Texture E" (UK), describing soft food with overall size less than 1.5 cm (British Dietetic Association, 2002; Dietitians Association of Australia & The Speech Pathology Association of Australia Limited, 2007).

The International Dysphagia Diet Standardisation Initiative (IDDSI; https://iddsi.org/) is an attempt to introduce a unified classification system (Cichero et al., 2013). IDDSI has seven classes for drinks and foods of which Class 6 ("soft and bite-sized") and Class 7 ("easy to chew") refer to solid foods. Class 7 consists of regular foods that are soft and tender and require teeth for chewing, whereas Class 6 includes solid, soft texture-modified foods that can be chewed without teeth. Class 5, "Minsed and moist," and Class 4, "Puréed," are semisolid and can be eaten with less oral strength. IDDSI gives a description for each class and empirical test methods such as fork or spoon pressure or chopstick puncture, but does not refer to physical measurements of mechanical properties, rheology, or texture (https://iddsi.org/).

Physical evaluation of texture is commonly made by deforming the food while monitoring resulting force, or by rheometry, and has been presented for various solid foods suitable for dysphagia patients (Drago et al., 2011; Lorieau et al., 2018; Park, Kim, Lee, & Park, 2017; Sungsinchai et al., 2019; Tokifuji, Matsushima, Hachisuka, & Yoshioka, 2013; Wendin et al., 2010; Yoshioka, Yamamoto, Matsushima, Hachisuka, & Ikeuchi, 2016). The impact of liquid consistency and food texture on swallowing behavior has been critically reviewed by Steele and coauthors, who concluded that: "Exceptionally limited information was available for objective measurement of texture-modified foods" (Steele et al., 2015). The majority of the studies of mechanical properties of texture-modified food is made by "Texture Profile Analysis," which is performed by compressing a cylinder of food in two cycles (Bourne, 1968; Szczesniak, Brandt, & Friedman, 1963). Various parameters with connection to food perception such as "hardness," "cohesiveness," "adhesiveness," and so on are extracted from force and deformation, which are recorded during two compression cycles. The method is simple and the meaning of the parameters is easy to grasp, but the method is not defined regarding sample size, amount of compression, and time between cycles (Peleg, 2019; Rosenthal, 2010). The results therefore depend on sample dimensions and measurement parameters and, for example, "cohesiveness" cannot be directly compared between different studies.

Geometry-independent material properties such as stress and strain should preferably be used, and a range of different parameters are needed for the characterization of a food material such as stresses and strains at fracture and yield (if present) and modulus. Having said this, foods are complex and often inhomogeneous, making physical, extensive properties (Peleg, 2019) impossible to determine. Size-dependent properties, such as penetration force, may therefore yield relevant information of the sample character, for example, to reflect surface hardness. Foods are generally viscoelastic and recorded stresses or strains will depend on the rate of deformation, and complementary rheological parameters are therefore necessary for a broader understanding of the food material behavior.

The general aim of the present study was to define a set of foods suitable for studies of solid, texture-modified foods, for later studies of boluses rheology specifically of solid, texture-modified foods. The specific aim of this paper is to characterize the material properties of carefully selected set of foods under conditions relevant for eating. As the paté class is moderately prescribed, focus was placed on the two other classes of solid, texture-modified food: timbale and gel. All foods were selected to form a meaningful combination in each texture class and were consumed at room temperature to minimize temperature effect. Bread is an important carbohydrate staple in Sweden and sandwiches are a dominant breakfast dish and popular in between meals, both as regular food and texture-modified food.

2 | MATERIALS AND METHODS

Ingredients and foods were chosen both to be similar to those used in elderly care and clinical kitchens and as much as possible, to be available in countries other than Sweden.

2.1 | Ingredients

Strained tomatoes without peel and seeds, produced in Italy, were obtained as "Coop Passerade Tomater" (COOP Sweden, Stockholm). Gelatine made from pig skin, Tørsleffs Favorit Gelatin, was sold by Haugen-Gruppen (Norrköping, Sweden). A starch-based thickener, "Thick & Easy" (Hormel Health Labs, Austin, MN) was kindly provided by Findus Special Foods (Malmö, Sweden).

2.2 | Food products

Regular foods were obtained from the local supermarket. Please see Figure 1 for the appearance of all food products.

- Bread: Kavring (Skogaholms Bageri, Sweden), a dark brown homogeneous bread without any seeds. The bread is sold presliced in 8 mm thick slices.
- Fresh tomatoes: The peel, interior fluid and seeds were removed before serving.
- Cheese: "Grevé," 17% fat (COOP Sweden, Stockholm), a Swedish semisoft cheese similar to the Swiss Emmental or British Cheddar.

Timbale foods were graciously provided by Findus Special Foods (Malmö, Sweden) as bread timbales and tomato timbales. Timbales are made from puréed food reconstituted by modified starch and egg to create a soft, moist consistency similar to the texture of an omelette. Timbales were distributed frozen, then thawed at room temperature (21°C) before measurements were made. In the Sweden system, processed cheese spread is used for both the timbale and gel food classes, and a processed soft cheese with 17% fat was used in this study ("Fjällbrynt Storsjö," Foodmark, Sundbyberg, Sweden).

The gelled bread was prepared according to how it is made in elderly and clinical care centers. For 30 min, a piece of bread was soaked in water thickened with oil (15 mL rapeseed oil and 7.5 mL Thick & Easy in 100 mL water heated to 80°C and cooled to 20°C). The gelled tomato was prepared from 100 mL strained tomatoes heated above 80°C and then 18 g of gelatine was added and stirred into the solution. The solution was cooled and kept at 8°C overnight before measurements were made.

2.3 | Methods

An Instron 5542 (Instron Ltd., Norwood, MA) was used for both the compression and penetration tests. Compression was performed on cylindrical samples (at least eight replicates) with height > diameter to avoid squeeze flow. The cylinders were cut from the foods and the diameter was chosen to optimize handling of the samples (see Table 1 for sample dimensions). The cylinders were compressed between two plates at a bulkhead speed of 50 mm/min to maximum 60% of the original height. Strains and stresses at fracture and at 60% strain, as well as Young's modulus, were extracted from the recorded deformation and force. The different foods have different Poisson's ratio and stress was calculated from the initial cross-section area. No food sample is perfectly flat, thus giving an initial lag in the recorded force, and Young's modulus was thus calculated as the maximum slope of the stress–strain curve in the interval 0–10% strain. Strain given in the figures is Cauchy strain,

$$\varepsilon_C = \frac{l - l_0}{l_0}, \tag{1}$$

where l is the sample height and l_0 is the original height of the sample.

Penetration tests were performed using a 4.8-mm-diameter probe at 1 mm/min penetration speed. The diameter and speed were chosen to enable comparison with previous studies. The apparent stress at 2 mm penetration and slope (modulus) was calculated. An apparent stress was calculated from the recorded force divided by the probe area. As the surface deforms this is not a uniform stress but gives more information than the force alone. Similarly, the slope of the apparent stress versus apparent strain (calculated equally to

TABLE 1 Diameter and height of samples for tests in compression

Food	Sample diameter (mm)	Average sample height (mm)
Bread	15.4	17.1
Bread timbale	10.4	10.8
Bread gel	15.4	20.0
Cheese	15.4	19.5
Tomato timbale	10.4	14.1
Tomato gel	10.4	13.0

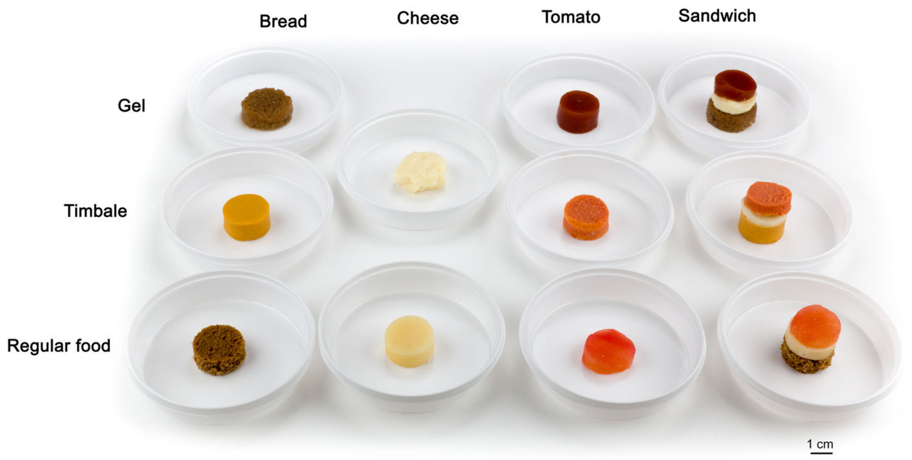

FIGURE 1 Photo of all foods used in the study. Note that soft cheese is used for both timbale and gel diets and that the figure shows food appearance and texture and does not reflect the size served nor the exact composition of the sandwiches

Equation (1)) gives an impression of the stiffness in penetration but is not equal to the Young's modulus.

Small amplitude oscillatory shear (SAOS) was performed using an ARES G2 (TA Instruments, New Castle, DE) equipped with a 40-mm-diameter parallel plate system and 2.5 mm gap. The bottom plate was temperature controlled and the measuring system was enclosed in a solvent-trap enclosure. Slices 30 mm in diameter and 2.5 mm thick were cut using a custom-made vacuum holder and a razor blade (Stading & Langer, 1999). The gelation and melting of the tomato gel were monitored using the same parallel plate system but with a gap of 0.8 mm actively adopting to changes in samples volume by temperature.

The complex shear modulus was monitored during heating from 20 to 37°C min to mimic the effect of temperature while ingesting a piece of the food. The maximum heating rate of the heating system of 15°C/min was used.

The moisture content (MC) of the foods was determined gravimetrically by at least triplicates before and after drying at 105°C for at least 18 hr. MC is calculated as the weight percent of water in the sample. Evaporation of other components at 105°C is assumed negligible.

Error bars in the figures present the *SD* of the mean value.

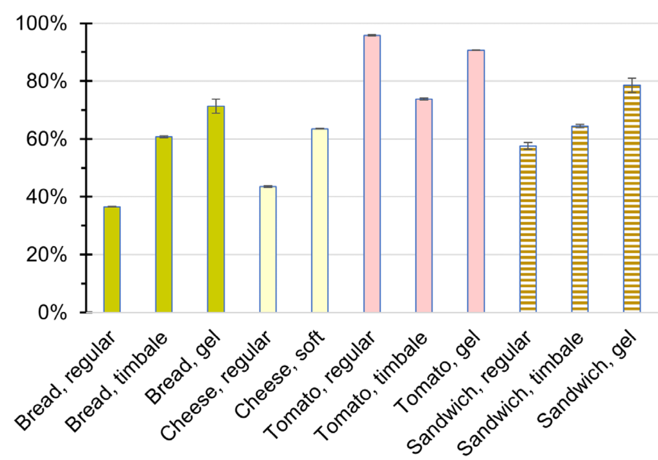

FIGURE 2 Moisture content (wt%) of the foods studied

3 | RESULTS AND DISCUSSION

3.1 | Moisture content

The MC of the food is presented in Figure 2. Moist foods are easier to form into a bolus and require less saliva, and the food classes consequently have MC in the order regular food < timbale < gel food. Tomato is the exception since a tomato contains about 95% water on a whole and the tissue used here had equally high MC. The timbales are all reconstituted from puréed food and produced to have both equal texture and MC, irrespective of food source, which is reflected in the data in Figure 2 where bread timbale, tomato timbale and the timbale combination (sandwich) all had similar MC. The soft cheese used in the timbale food class is not reconstituted the same way, but still has similar MC compared to the timbales, and higher MC than regular cheese. Note that soft cheese is used for dysphagia patients following both timbale and gel food diets.

Sandwiches were made in the respective food class by combining bread, cheese, and tomato in the weight ratio 2:1:1.5 which equals 44.4% bread, 22.2% cheese, and 33.3% tomato. This corresponds to the composition of a typical, regular sandwich. The respective MC is given in Figure 2, mainly as a reference for future studies, and they follow the expected MC for the respective food considering the weight ratio used.

3.2 | Mechanical properties

The mechanical behavior of the different foods was monitored in compression and penetration, and an example of the stress–strain curves is shown in Figure 3 for bread, bread timbale, and bread gel. Already in the shape of the stress–strain curves, there is a distinct difference between the food classes. The stress level follows the order

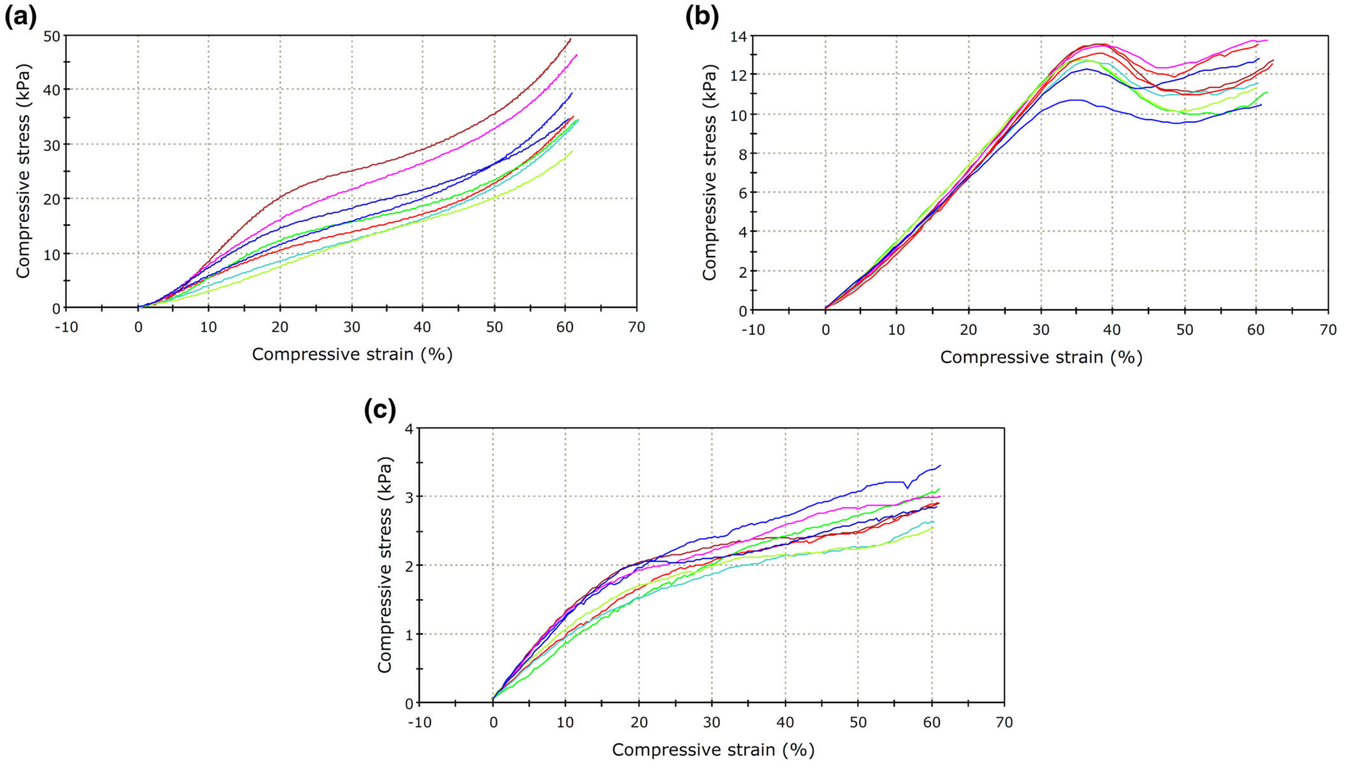

FIGURE 3 Stress–strain curves for compression of (a) bread, (b) bread timbale, and (c) bread gel. The three diagrams show all replicates

bread > bread timbale > bread gel. In terms of oral perception, the stress level corresponds to the "strength" or "hardness" experienced when chewing and biting into the food. Figure 3 shows that the bread timbale fractures at 35% strain (Figure 3b), whereas the stress for regular bread and the bread gel increases continuously with increasing strain (Figure 3a,c).

Stress and strain at fracture was extracted from the stress–strain curves for all foods along with the stress at a specific strain of 60%, and Young's modulus (see Figure 4).

The modulus is the initial slope of the stress–strain curve and in terms of oral perception it may corresponds to the "chewiness" or "stiffness" experienced before the food breaks even if there is no straight relation. The term "Max stress" in Figure 4c denotes the highest stress in the strain range applied, 0–60%, which means either the fracture stress, or the stress at 60% strain for the samples, is not fracturing.

Figure 4 reinforces the observation that the regular foods are "harder" or "stronger" than the timbale foods, which in turn are "stronger" than the gel foods. This is the intention when designing texture-modified foods, and it has been achieved through an appropriate choice of ingredients and processing, as well as recipe development based, on patients' and caregivers' experience. These foods are known to be easier to chew and swallow for those suffering from different degrees of dysphagia, even if both the flow of the boluses of these foods and the physiological responses are not studied in detail.

A further observation in Figure 4 is that when the regular cheese is in every respect hard, the maximum stress and modulus were considerably larger than that of any of the other food. When eating this cheese, there is also a combined action of saliva and elevated temperature when forming a bolus. Lorieau and coauthors have concluded that although such cheese was perceived hard as compared to, for example, soft cheese by an elderly sensory panel (66–86 years), it was still perceived moderately easy to form a bolus (Lorieau et al., 2018).

Penetration testing complements the information from the compression tests and relates primarily to how we perceive biting into the food using our teeth. The penetration stress was higher for regular tomato than for regular cheese, although the cheese was much harder in all other aspects, which reflects the initial fracture behavior (see Figure 5). It is relatively easy to bite into the cheese as expressed by the penetration force, but further compression requires oral strength, suggesting that small pieces of cheese should also be manageable for people with impaired oral strength as long as their teeth are intact.

Note that both apparent penetration stress and modulus are calculated as force divided by probe area. By no means does it indicate that they present a uniform stress or modulus, but rather offer a possibility of comparison of magnitude to other measurements. The penetration results should be used primarily as a measure of the effects of the first bite.

The mechanical behavior of the foods can be compared to other published studies. Wendin and coauthors determined penetration behavior of timbale and gel foods (Swedish classification system) and found similar ranges of penetration stress: 30–45 kPa for timbales and 4.4–14 kPa for gel foods (Wendin et al., 2010). Most national

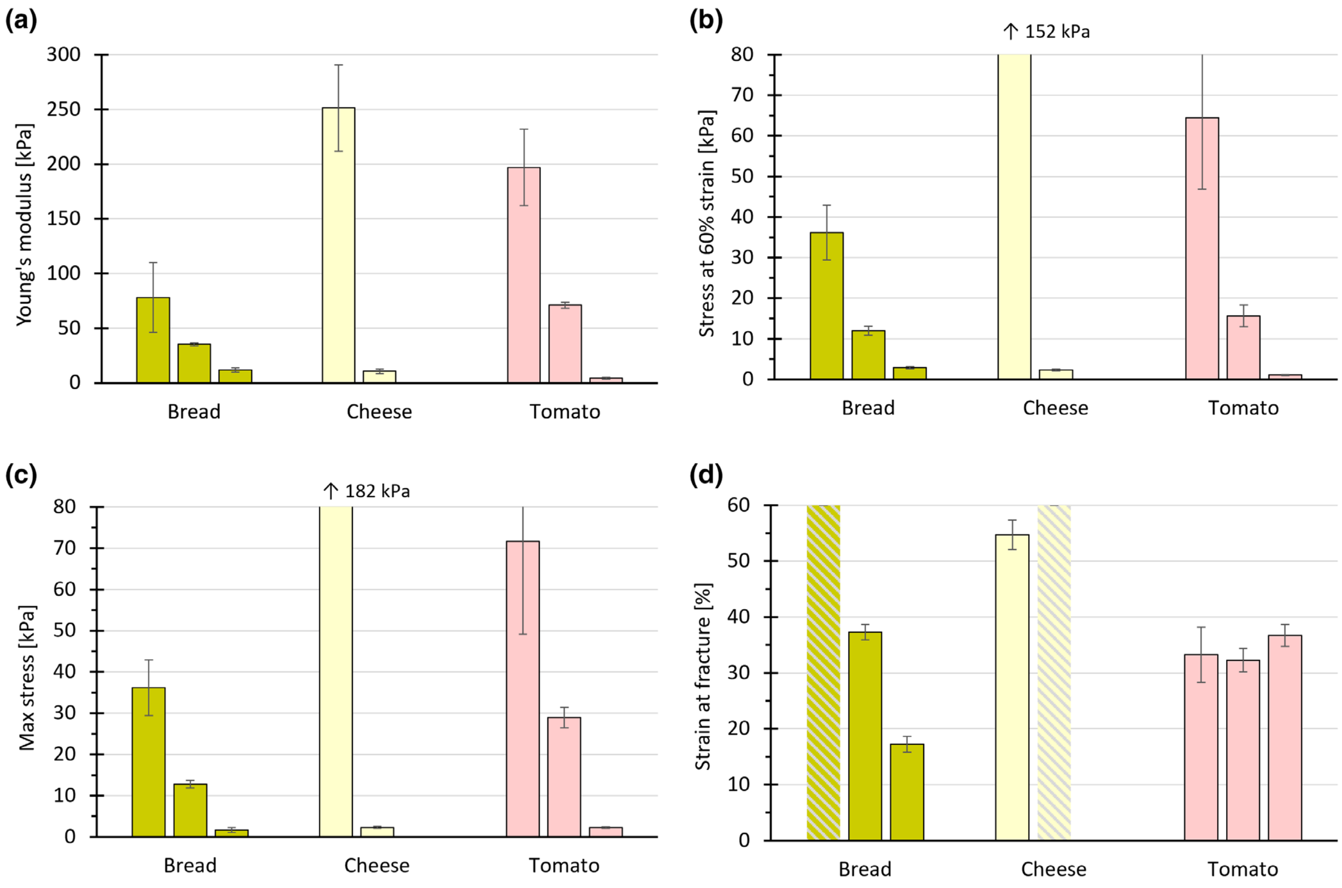

FIGURE 4 Fracture properties in compression for the different foods. The first bar in each group is for the class "regular food," and both the second and third timbale are for "gel food." For cheese, soft cheese is used for both timbale and gel food. (a) Modulus, (b) stress at 40% strain, (c) maximum stress, and (d) strain at fracture. The shaded bars in (d) refer to the maximum strain as these foods did not fracture

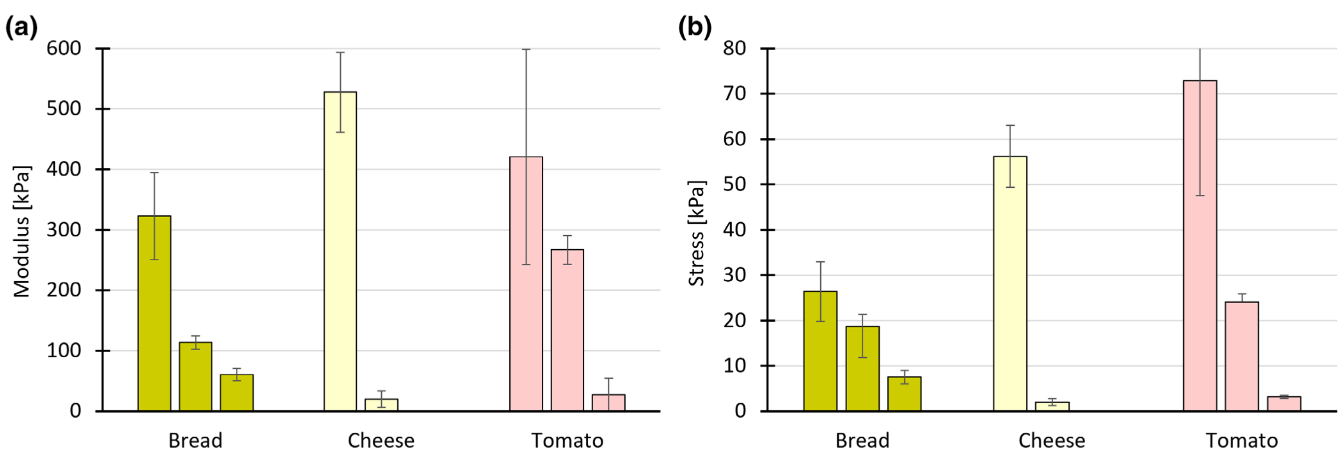

FIGURE 5 Fracture properties in penetration for the different foods. The first bar in each group stands for the class "regular food," and both the second and third timbale are for "gel" food. For cheese, soft cheese is used for both timbale and gel food. (a) Apparent modulus and (b) apparent stress at 2 mm penetration

classification systems for texture-modified foods, as well as the international IDDSI system, are based on the assessment of texture from visual inspection and empirical tests. Furthermore, it is difficult to make the comparison with other published mechanical tests of texture-modified foods, as the great majority of the data is from "texture-profile analysis," TPA, and experimental parameters are generally not given. If sample geometry and maximum deformation in the first compression cycle would had been given, it would at least have been possible to compare the TPA "hardness" with compressive stress at the same compressive strain. Japan has a similar classification system to that of Sweden, and Japanese studies refer to a standard method by the Japanese Ministry of Health, Labour and Welfare (Ministry of Health Labour and Welfare, 2009), which has moved to the Japanese Consumer Affairs Agency. The standard is published in Japanese, but provides the compression ratio for the first TPA cycle to be 2/3, or 70%, but with a 20-mm-diameter cylindrical plunger compressing a sample in a 40-mm-diameter cup. This results in a complex stress distribution, but allows for at least an approximate comparison.

There is a recent explanation in English of the Japanese Dysphagia Diet (JDD2013) (Matsuo & Fujishima, 2020). In JDD2013 gel foods containing protein have "hardness" <12 kPa, which is a considerably higher limit than measured for the gel foods in the present study that have max stress <2.3 kPa. Gel foods are unusual in modern Swedish cuisine, but are much more common in Japan, which may be part of the explanation. A wider variety of gel food textures in Japan would also include harder gels requiring higher stresses during mastication. The different measurement method may also give rise to a difference as compression in a cup gives higher forces due to the contribution of "back extrusion" along the sides of the plunger, as compared to free compression of a cylindrical sample between two plates with a diameter larger than the sample.

Timbale food is comparable to JDD2013 code 3, which are solid foods that can be crushed without the use of teeth and are specified to have "hardness" <40 kPa. In the present study, timbale foods have max stress <29 kPa, which corresponds to JDD code 3 (Matsuo & Fujishima, 2020). Yoshioka et al. reported a hardness, similar to stress 70% compression, in the range 28–100 kPa for minced fish gels, which were high pressure or heat treated, and concluded that they would be suitable for dysphagia diet code 3 or 4 (Yoshioka et al., 2016). Tokifuji reported hardness obtained with the same method to be in the range of 15–44 kPa for high-pressure treated pork meat and concluded that the gel with hardness = 15 kPa was suitable for a dysphagia diet (Tokifuji et al., 2013). Park et al. reported hardness values of 25 kPa for soft boiled rice, which was considered suitable for mild dysphagia (Park et al., 2017).

Timbales are served to Swedish patients who may have impaired dental status but can crush the timbales between the tongue and the palate, even though the "hardness" is higher than recommended for dysphagia patients in Japan. Part of the discrepancy could be explained by the difference in the measuring method as mentioned above, but it is also in line with preliminary studies indicating that tongue strength is lower among Japanese as compared to Swedes (unpublished data). There are no studies published on tongue strength in a Swedish population, but reported results claim that tongue strength is higher in a US group of subjects as compared to both Japanese and Belgian similar groups, and the Belgian group is higher than the Japanese group (Utanohara et al., 2008; Vanderwegen, Guns, Van Nuffelen, Elen, & De Bodt, 2013). The studies are, however, made with different instruments and instrumental differences cannot be ruled out. More important is that the comparison of food texture in relation to national classes highlights dissimilarities in the national dysphagia system and the need for objective, intensive material properties for physical classification of texture-modified foods.

3.3 | Effect of temperature

All foods in this model set were chosen as food products consumed at room temperature. The model set is designed to be used in studies of bolus properties and it is desirable to minimize the impact of environmental parameters such as temperature. Temperature has a direct effect on rheological properties and foods served cold or hot will have a different oral temperature profiles. Even food served at room temperature will change when consumed and the temperature effect is presented in Figure 6. The complex shear modulus was monitored during heating from 20 to 37°C at 15°C/min and initial and final storage modulus and phase angle are presented in the figure. The storage modulus decreases with temperature as expected, except with soft

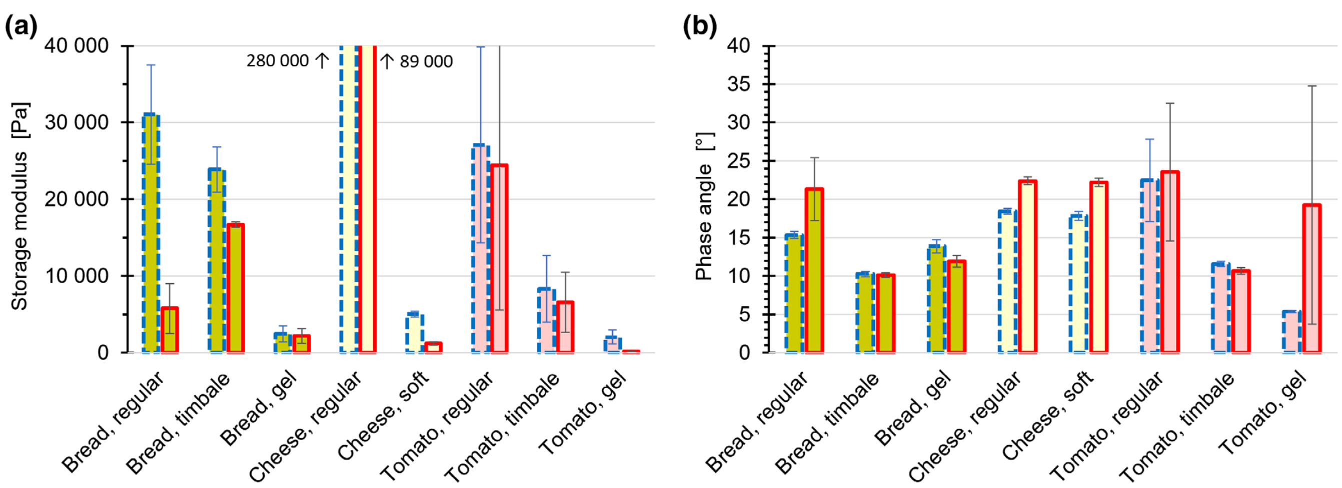

FIGURE 6 Storage modulus (a) and phase angle (b) of the foods at 20 and 37°C. Bars for 20°C have a dotted, blue stroke and bars for 37°C have a solid, red stroke

cheese. Wendin and coauthors determined storage modulus of timbale and gel foods and found similar ranges: 15–17 kPa for timbales and 0.8–1.6 kPa for gel foods (Wendin et al., 2010).

For most of the foods studied, the decrease in storage modulus with temperature is caused by the expected effect of thermal energy progressively exceeding attractive forces in the food without any temperature induced transitions occurring. However, for the tomato gel and the hard cheese, there are transitions. The tomato gel is based on gelatine which melts at mouth temperature. Similarly, the fat in the cheese also melts.

Temperature is just one effect the food is subjected to during oral processing and the addition of saliva and the mechanical energy by mastication both have a larger effect than temperature alone on most foods. This is however out of scope for the present study and will be described in subsequent papers.

4 | CONCLUSIONS

A model system for solid, texture-modified foods was developed and characterized. It ranges from regular food (bread, cheese, tomato), smooth timbales (bread, cheese, tomato) to gel food (bread, cheese, tomato), as well as the combinations of these foods into sandwiches in the classes regular food, timbale and gel food. The foods were selected to be eaten without prior heating to avoid temperature effects. The modification classes were chosen according to the Swedish system and compared with other national and international systems.

The texture-modified foods were "softer" in all aspects as compared to the regular foods: compressive max stress, penetration stress and modulus were all progressively lower, decreasing from regular food to timbale foods to gel foods. The texture-modified foods were also progressively moister as measured by the MC.

The classification system in Sweden is comparable for solid foods to other national systems, but not comparable directly, as there is a lack of objective, physical classification of the texture of the modified foods. Moreover, the common texture profile analysis used for texture classification is rarely presented with enough experimental parameters to enable comparison with extensive physical properties.

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AUTHOR CONTRIBUTIONS

Mats Stading: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; validation; visualization; writing-original draft; writing-review and editing.

ETHICAL STATEMENTS

Conflict of Interest: The author declares that he does not have any conflict of interest.

Ethical Review: This study does not involve any human or animal testing.

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